BEST PRACTICES IN GOVERNMENT ACQUISITION:

A TEST OF THE GOVERNMENT ACCOUNTABILITY OFFICE'S KNOWLEDGE-BASED ACQUISITION THEORY

THESIS

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Abstract

The U.S. Government has looked for effective ways of reducing acquisition cost and schedule overruns for decades. The task of isolating the root cause of these overruns has been difficult. Consequently, it has been difficult for the Government to create effective policies that prevent overruns from recurring. In 1998, the Government Accountability Office (GAO) undertook this problem, and looked to successful DOD and commercial companies for solutions. They found that using mature technology, having complete product designs, and having production processes under control was critical to successfully developing new products. The GAO combined these concepts into a single acquisition practice that they call a *Knowledge-Based Approach.* They postulate that programs that adhere to the *Knowledge-Based Approach* will experience better program outcomes than programs that do not. This thesis validates the GAO's claim by comparing the outcomes of programs that met the *Knowledge-Based Approach* criteria with those that did not. Our findings suggest that the GAO's claim is accurate. While their approach may not be a single means for success, programs that employed their approach generally performed better. The programs that met the GAO's criteria experienced a smaller variation of outcomes and appeared less likely to spiral out of control.

I dedicate this work to my wife and daughter. Their support and sacrifice have allowed me to complete this study on time and on budget.

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I: Introduction

Introduction

The U.S. Government has searched for effective ways of reducing its acquisition cost and schedule overruns for decades (Deloitte Consulting LLP, 2008; Hanks, Axelband, Lindsay, Malik, & Steele, 2005; GAO, 2002). Acquisition reform efforts have been around for decades, yet acquisition program outcomes have improved very little (Friedman, 2009; Hanks, Axelband, Lindsay, Malik, & Steele, 2005). The ineffectiveness of current acquisition practices is a challenge, and has limited the DOD's ability to supply the warfighter with systems on time and on cost (Shimel, 2008). Poor acquisition program outcomes have become notorious throughout the DOD, as they have become a hindrance to the acquisition customer, as well as to internal and external acquisition stakeholders. Deloitte Consulting conducted a survey of government and Aerospace & Defense executives regarding program execution problems. Deloitte found that over 43% of government and Aerospace & Defense executives polled thought that program execution problems were as serious as the current housing and banking crisis (Deloitte Consulting LLP, 2008, p. 1). Additionally, because of Congress's concern with program performance, Congress has established mandatory reporting requirements for

those programs in which unit cost has exceeded 15 percent of the originally planned cost (Shimel, 2008).

The DOD acquisition portfolio is enormous, containing 96 major programs valued at approximately $1.6 Trillion in 2008. Further, the cost growth of these programs in 2008 was valued at $296 Billion and the average program was 22 months behind schedule (GAO, 2009, p. 7). On average, cost and schedule overruns have been increasing by roughly 1.86 percent annually and it has been estimated that they will increase from the already high rate of 25 percent in 2009, to over 46 percent by 2018 (Deloitte Consulting LLP, 2008, p. 2; GAO, 2009).

In 2009, the VH-71 program experienced a unit cost growth of fifty percent from its estimate in 2006, and it cut its production quantity in half (Fein, 2009; GAO, 2009). The VH-71 program's overrun was a Nunn-McCurdy Breach, wherein the Secretary of Defense must certify that the program meets several requirements in order to keep the program "alive" (BNA Federal Contracts Daily, 2007). The user will receive half the units they expected and will pay more for them. This is not atypical, programs like the C-130 Avionics program, the Expeditionary Fighting Vehicle, the Joint Air-to-Surface Standoff Missile, the Land Warrior, and the Warfighter Information Network all suffered Nunn-McCurdy breaches due to unit cost growth of more than 25% of their current baseline or 50% over the Approved Program Baseline (BNA Federal Contracts Daily, 2007). Clearly, a need exists for more effective acquisition practices to improve this trend and help programs stay within cost and schedule estimates.

The Current Acquisition Movement

The Office of the Assistant Secretary of the Air Force published the *Acquisition Improvement Plan* in 2009. Their focus was on recapturing acquisition excellence by establishing an acquisition framework that instilled rigor, reliability, and transparency in the acquisition system. The *Acquisition Improvement Plan* required the use of incremental acquisition strategies that reduced cost, schedule, and technical risk, while producing operational capabilities early (Office of the Assistant Secretary of the Air Force, 2009). Lastly, the plan sought to "implement means to increase cost estimating confidence levels and establish more realistic program budgets (Office of the Assistant Secretary of the Air Force, 2009)." We suspect that the Government Accountability Office's (GAO) *Knowledge-Based Approach* was influential in the creation of these goals. The GAO's *Knowledge-Based Approach* centers on the concept that programs can achieve better results by reducing their technology risk early in the program lifecycle. Thus, the GAO's approach should be an effective way for programs to achieve the challenging demands of the *Acquisition Improvement Plan.*

The GAO Studied Best Practices

The GAO conducted an in-depth study of the best practices used by DOD and Commercial industry and then used their findings to develop the *Knowledge-Based Approach.* Their goal was to help program managers achieve better program outcomes by leveraging the acquisition community's best practices (GAO, 1998). The GAO acquired these best practices through interviews of what they considered the best DOD

and commercial companies with regard to developing and manufacturing new products (GAO, 1998). The GAO found that an important characteristic of successful commercial and DOD organizations was that they had attained essential knowledge of their programs at or before critical points in their new-product development processes. These programs had mature technology prior to program initiation, they had complete product designs prior to their product design review, and they had their production processes under control before beginning production.

Consequently, the GAO recommended that the DOD adopt these practices through an approach the GAO calls the *Knowledge-Based Approach.* The GAO believes that this approach will help DOD programs achieve better program outcomes based on the GAO's extensive study of new-product development best practices (GAO, 1998; GAO, 2002). This approach has been instrumental to the success of commercial firms like Boeing, Chrysler Corporation, Cummins Engine Company, Ford Motor Company, Honda Motor Company, and Hughes Space and Communications, all considered among the best organizations in developing new products (GAO, 1998, p. 3).

Follow-up Assessments

The GAO collected program performance data on major acquisition programs as a follow-up to their original study. Each program was chosen because of its high dollar value, acquisition stage, or because it had attracted congressional interest (GAO, 2008). The data sources included the Selected Acquisition Reports and the Defense Acquisition Management Information Retrieval Purview system, which provided the financial, schedule, and quantity information for each program. Additionally, the GAO used

questionnaires and interviews to gather information about program office staffing, program requirement changes, and other program aspects (GAO, 2009). The GAO has presented their audit findings annually, beginning in 2003, in GAO reports titled *Assessments of Selected Weapon Programs.* As we will discuss, these reports were the basis of our analyses.

Purpose of This Study

The objective of our study was to test the GAO's Knowledge-Based Approach (hereafter termed the *Knowledge-Based Acquisition Theory (KAT)),* to determine if programs that met the *KAT* criteria performed better than those that did not. By testing the *KAT,* we felt we would better understand the relationship between the *KAT* and program performance, thus giving additional credence to the GAO's methodology. Our test focused on the following research question:

Research Question:

> Do defense acquisition programs that adhere to the GAO's *Knowledge-Based Approach* perform***** better than programs that do not?
>
> *******Performance measured using cost, schedule and quantity variables.*

This study will contribute to the "Acquisition Community of Practice" (Defense Acquisition University). Our results will provide program managers with a better understanding of the implications of their decisions regarding the GAO's *Knowledge-Based Approach*. Furthermore, isolation of the factors most critical to program success

will help decision makers better understand the trade space surrounding their decisions, as well as better understand the potential consequences of their decisions.

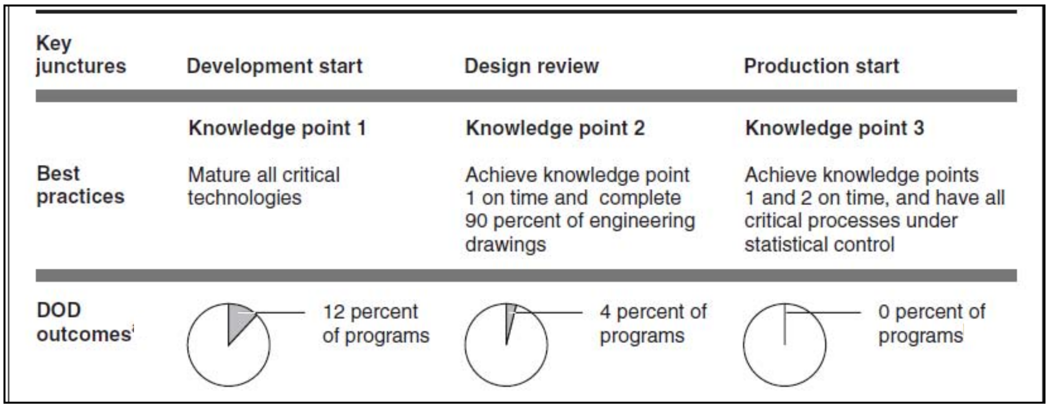


Figure 1: Knowledge Assessment for Weapon System Programs in 2008

(GAO, 2008)

The GAO's *Knowledge-Based Approach* seems to be a logical approach to obtaining better program results. However, in 2008, the GAO reported that none of the programs they assessed at Milestone C (Production Start) had achieved the respective *Knowledge-Based Approach* criteria, and that 88 percent of programs were initiated (Development Start) without mature technology (Figure 1). We anticipate that our findings will confirm the GAO's claim that programs that adhere to the *Knowledge-Based Approach* will experience better outcomes, and that our findings will encourage program managers to adopt the GAO's *Knowledge-Based Approach.*

We organized the remainder of this document as follows: Chapter II provides an in depth look at the Knowledge-Based Acquisition Theory as well as a historical glance

at previous acquisition reform efforts. In Chapter III, we explain our data source and the variables we used for our analysis. We also explain the methods we used to test our hypotheses. In Chapter IV, we describe the results of our analysis. Lastly, in Chapter V we summarize the results and suggest the policy and procedure implications of our results.

II: Literature Review

Introduction

Over the past twenty-five years, acquisition reform initiatives have focused on ways to improve the efficiency and effectiveness of acquisitions, so that the Department of Defense (DOD) can reduce cost and schedule overruns (Hanks, Axelband, Lindsay, Malik, & Steele, 2005; Christensen, Searle, & Vickery, 1999). The GAO has offered its *Knowledge-Based Approach* as an effective way for the DOD to improve acquisition program outcomes, based on the results of GAO's study of best practices within DOD and industry (GAO, 1998). Although the GAO's approach has influenced the Acquisition Improvement Plan, the GAO's approach has not been readily adopted, and the management and execution problems have become "too big to ignore" (Deloitte Consulting LLP, 2008).

Department of Defense (DOD) acquisition programs continue to have cost and schedule overruns (GAO, 2002, p. 2; Deloitte Consulting LLP, 2008; Schwartz, 2009). These overruns reduce the DOD's buying power and reduce the funding available for other DOD priorities (GAO, 2008, p. 5; Gansler, 1989, p. 170). Overruns are not new to DOD acquisitions. However, overruns are often viewed as singular events, rather than systemic ones (Shimel, 2008). Further, cost and schedule growth has invoked concern from both Congress and the American public in the DOD's ability to meet the urgent and growing needs of the warfighter (GAO, 2005; Schwartz, 2009). In 2009, the DOD acquisition portfolio was valued at $1.6 Trillion, and the portfolio had accumulated an estimated $296 Billion in program cost growth (GAO, 2009). This cost growth is

equivalent to the pay and expenses of all members of the armed services for two years (111-23, 2009, p. 12). These persistent cost and schedule overruns make it hard for the DOD to accurately forecast its financial requirements and have been the catalyst motivating the DOD and Congress to pursue more efficient acquisition practices. (GAO, 2009, p. 9)

Background

Congress and the DOD have looked for ways to improve the acquisition process for decades (Christensen, Searle, & Vickery, 1999; Hanks, Axelband, Lindsay, Malik, & Steele, 2005; The President's Blue Ribbon Commission on Defense Management, 1986). Each increment of change that has been implemented has attempted to make DOD acquisitions a more efficient and effective process. However, the reform initiatives from the 1960s to the 1990s brought little improvement to the effectiveness of the system as indicated by a consistent cost growth of approximately twenty percent throughout that period (Christensen, Searle, & Vickery, 1999, p. 4). During the 1980's, reform initiatives focused on fraud, waste, and abuse. However, the focus changed in the late 1980's when it became apparent that the cost of fraud, waste, and abuse was inconsequential compared to the cost of the heavily legislated procurement process (Hanks, Axelband, Lindsay, Malik, & Steele, 2005).

Consequently, in 1986 President Reagan initiated significant changes to the acquisition process. At that time, the overall sentiment toward DOD acquisitions was that the DOD needed to become more "responsive, effective, and efficient" in its

acquisition practices (Hanks, Axelband, Lindsay, Malik, & Steele, 2005). Consequently, President Reagan appointed Mr. David Packard to direct the "Presidents Blue Ribbon Commission on Defense Management" in 1985. The Packard Commission spent a year studying ways in which the DOD could improve its management through an in depth look at both government and commercial companies that produced similar products to those produced in the DOD. The commission focused on the underlying business models of successful companies to see what models they could use as a foundation for an improved DOD acquisition model. As we will discuss later, the approach taken by the GAO in 1998 was very similar to the approach taken by the Packard Commission in 1986.

The Packard Commission found that the DOD needed to reduce the "red tape" that was restricting its employees from being efficient. They also found that the current process was "inflexible," and that the legislation was often the cause of the waste it aimed to eliminate (President's Blue Ribbon Commission on Defense Management, 1986). As a result, their efforts aimed at reducing the "bureaucratic inefficiencies" found in the system by consolidating acquisition legislation and streamlining the process (President's Blue Ribbon Commission on Defense Management, 1986).

In addition to finding ways to streamline the process, the 1986 Packard Commission examined how *technology push* and *user pull* could have specific implications on government acquisitions (The President's Blue Ribbon Commission on Defense Management, 1986). As they described, a *user pull* situation occurs when users assess their current capabilities and then request new assets to fill any capability deficiencies (President's Blue Ribbon Commission on Defense Management, 1986). It is

an effective approach in terms of keeping the requirements generation process requirements driven since the users are generating requirements based on current needs, and not on a desire to have a "new" technology. Unfortunately, the typical user is unfamiliar with the technology development process and usually has only a limited understanding of the implications of their "requests" (President's Blue Ribbon Commission on Defense Management, 1986). A *technology push* situation occurs when new technologies are "sold" to users. Users then generate requirements based around the new concepts. As we will discuss later, the GAO's KAT recommends that new product development requests originate from user-defined ("user pulled") capability gaps and that the acquisition community fill gaps using existing, mature, technologies (GAO, 1998, pp. 24-25)

Post 1986 Packard Commission Reform

For more than a decade following the 1986 Packard commission, acquisition reform focused on ways to achieve quicker, more efficient processes. Throughout the 1990's the DOD implemented over sixty acquisition reform initiatives focusing on "faster, better, and cheaper" acquisitions (Hanks, Axelband, Lindsay, Malik, & Steele, 2005) . These initiatives focused on helping the DOD expedite its acquisition processes and allow it to take an aggressive approach to new product development. These changes included streamlining the acquisition hierarchy, applying "off-the-shelf" components to new products, and using cost and performance tradeoff studies when determining program requirements (Templin & Christensen). However, the reform initiatives in the

1990's also led to a significant reduction in the size of the government acquisition workforce, and in turn led to an increase in outsourcing (Thomas, 2008).

After 2001, the reform focused primarily on improving accountability and oversight (Hanks, Axelband, Lindsay, Malik, & Steele, 2005). In addition, current reform has placed the burden of program performance on the program manager (Hanks, Axelband, Lindsay, Malik, & Steele, 2005, p. 17). Managing a program is a daunting task during a time when much of the program execution responsibility rests with the major defense contractors (Deloitte Consulting LLP, 2008, p. 16). Defense contractors are making important decisions regarding system requirements and design, and in many cases, defense contractors decide who will be developing system subcomponents (GAO, 2005). This environment can add risk to DOD acquisition programs if not properly managed (Hillson, 2004, p. 13).

GAO's KAT

The GAO has recommended that the DOD implement a Knowledge-Based Acquisition approach since 1998. In 1998 and again in 2002, the GAO testified before Congress that their research showed that commercial industry had achieved better new-product development outcomes by developing products using only proven technology, completed product designs, and by having their production processes under statistical control (GAO, 1998; GAO, 2002). However, over the past ten years, program managers have not fully adopted the GAO's guidance into their decision making process based on the results of the GAO's surveys (GAO, 2009). Why? Has the "persistent nature of

acquisition problems" overwhelmed decision makers, making them complacent (GAO, 2005)? Is the DOD so unique as to be unable to achieve results similar to successful commercial firms?

DOD versus Commercial Industry

There is a significant difference between the DOD's pursuit of new-product development versus that of the commercial sector. One such difference is the amount of responsibility each program manager has for program outcomes. Program managers in the companies the GAO visited were incentivized to be realistic about their ability to meet their program goals since these managers were likely to stay with a program from concept to production (GAO, 2000, p. 1). As a result, commercial program managers are probably less likely to be overly optimistic about their program metrics.

Department of Defense program managers have short tenures relative to their commercial counterparts. The program manager who establishes the initial cost and schedule expectations is usually not accountable for achieving those expectations (GAO, 2000, p. 9; Deloitte Consulting LLP, 2008). This environment holds managers accountable to near term program issues, but they are less accountable for the long-term viability of their programs. We do not suggest that government managers are dishonest, merely that they are incentivized to be more focused on the near term aspects of the program and less on the long-term impacts of their decisions.

Furthermore, it is likely that a commercial manager's promotion potential is tied more to the successes and failures of the programs they have managed than is the

promotion potential of a DOD manager. As a result, the commercial program manager is less likely to take on undue risk or attempt to inflate the reputation of their programs (GAO, 2002, pp. 3-10; GAO, 2000, p. 6). On the other hand, DOD program managers promotion opportunities are often tied less to the long-term performance of their program and more to its performance during their tenure (GAO, 2000, pp. 2-3). Department of Defense program managers typically change many times throughout the life of the program making it hard to associate any single success or failure to a specific individual.

Additionally, a DOD program manager is motivated to obtain funding each year, and to be an advocate for their program and the user (GAO, 2000, p. 3; Deloitte Consulting LLP, 2008, pp. 15-16). Managers' incentives are to take on risk, and to pursue an aggressive budget, schedule, and performance goal. The importance of this is that a commercial program manager may view the *Knowledge-Based Approach* as an appropriate way to ensure successful outcomes, while a DOD program manager may see the *Knowledge-Based Approach* as a hindrance that slows down the pace of his or her program.

In addition to having different incentives for their managers, DOD and commercial firms pursue new product development for different reasons. The DOD's mission, to supply national defense, requires that it constantly develop new products for use in maintaining its military supremacy. The DOD does not seek to profit like commercial business; however, it is motivated to minimize cost because of congressional pressure and a limited budget. Commercial firms are motivated by profit generation, which also demands that they limit their costs in order to be successful. Consequently, commercial firms initiate new product development only when a solid business case

exists, or a market need exists. Commercial firms initiate new product development when they are certain they can produce a product in a relatively short time period and when the technology needed for the product has already been demonstrated (GAO, 1998, pp. 5-7; GAO, 2000, p. 4). Therefore, while the incentive structure and reasons are different, the DOD and Commercial Industry both seek to minimize the cost and time needed to produce a new product.

GAO's Knowledge-Based Acquisition Theory

Our analysis focused on testing the assumptions of the GAO's Knowledge-Based Acquisition Theory (KAT). In 1998, at the behest of Congress, the GAO studied whether or not "commercial practices offer ways to improve DOD's process for transitioning weapons from development to production (GAO, 1998)." The subsequent GAO report focused on three things. First, it compared DOD's practices for preparing a weapon system for production and the best practices used by commercial firms for similar projects. Second, it examined how the environments that the DOD and commercial firms operate in affect their new product development practices. Lastly, the report discussed environmental changes that the GAO considered "key to the success of DOD initiatives for improving the transition of weapons from development to production" (GAO, 1998). The purpose of GAO's study was to help the DOD find effective ways of expediting acquisition schedules and to help programs become more effective (GAO, 1998). The GAO wanted to help find a way for the DOD to get product development results similar to those found in industry.

There is a significant difference between the DOD and commercial sectors management of the technology used in their new-product development (GAO, 1998, p. 12). Commercial companies make a distinction between technology development and product development; they keep the two activities independent of one another (GAO, 1998, p. 12). Commercial new-product development includes designing and manufacturing of a particular product that meets the needs of a particular market.

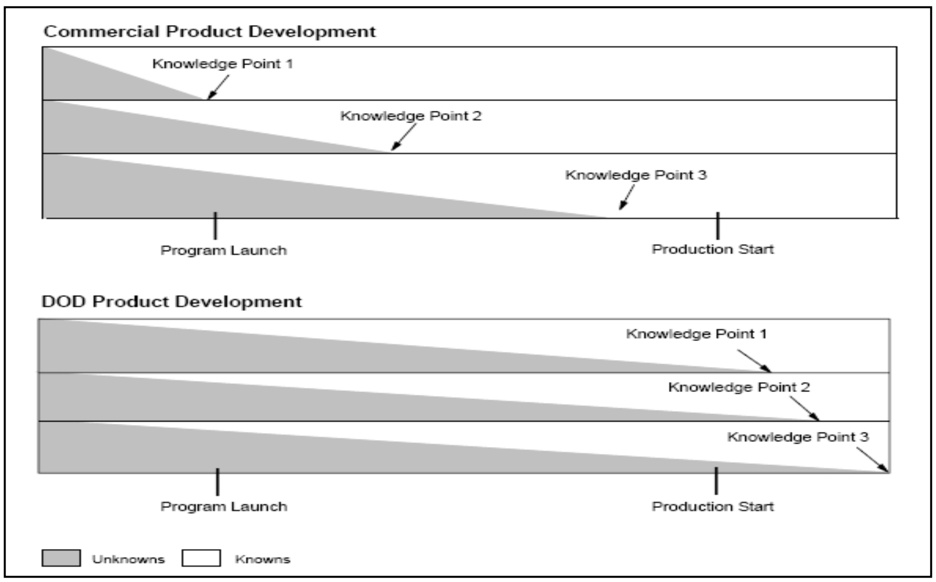


Figure 2: Achieved Technology Development (GAO, 1998)

Conversely, new-technology development, independent of new-product development, looks to advance current technology so that it will be available for use in future products. Commercial firms separate technology and new product development because they view technology development as volatile and risky, and they expect it will require a lot of rework (GAO, 1998, pp. 12-14; GAO, 2000, p. 4). In the DOD,

technology development and product development typically occur in unison as part of one acquisition strategy; the technology that is developed focuses on a specific need for a specific product. The DOD takes on the risk inherent in new technology development during new product development.

Figure two shows how differently commercial firms and the DOD approach technology development completion (Knowledge Point 1) with respect to new product development (program launch). The commercial firms have completed technology development prior to new-product development, whereas the DOD will continue to develop its technology well into production (GAO, 1998, pp. 14,22; GAO, 2005, p. 7).

Commercial practices may not be readily adaptable to the DOD's acquisition environment. Unlike commercial organizations, the DOD develops cutting-edge products that test the limits of technology so that it can maintain military supremacy. Further, because the DOD already has "first-class" products in its inventory, new products must be even more advanced than the current inventory to be developed (Friedman, 2009). Nevertheless, if the DOD seeks program outcomes that are similar to those found in successful commercial firms, it may benefit from studying their methods. The GAO's *Knowledge-Based Approach* derived from their research of successful commercial firm practices.

Knowledge Point 1: Mature Technology

The GAO's knowledge point one is synonymous with Milestone B for DOD programs, and it is the first of the three KAT criteria that the GAO expects will lead to

"better weapon system outcomes" (GAO, 1998). A product must have obtained a *technology readiness level* of seven (*TRL7*) at or before KP1 in order to meet the GAO's best practice standard. In other words, a product's technology must work in its intended operational environment (see appendix for complete TRL definitions). This is different from current DOD practices, as current policy requires programs to have met *TRL6.* Technology Readiness Level 6 demonstrates technology maturity at the subcomponent level, not the integrated system (USD(AT&L), 2008).

According to the GAO, successful commercial firms match mature technology with system requirements at KP1 and then proceed to produce the new product. Successful commercial firms do not usually develop a new technology for a new product since technology development is expensive and time consuming. Instead, they design new products around pre-existing and mature technology (GAO, 1998).

In 2006, Congress required that Major Defense Acquisition Programs (MDAPs) demonstrate *TRL6* prior to obtaining milestone B approval (Office of Air Force Lessons Learned (HQ USAF/A9L), 2009). This requirement is similar to the recommendation made by the GAO; however, the difference between *TRL 6* and *TRL 7* is significant. According to the GAO, *TRL 7* "represents a major step up from *TRL 6*," as it signifies that the prototype works in an operational environment on an actual system (GAO-09-326SP). The standard for *TRL 6* is that a prototype works in a realistic environment such as a "high fidelity lab" or a "simulated realistic environment" (GAO-09-326SP). Similarly, The Technology Readiness Assessment (TRA) Deskbook states that technology should be proven in either a relevant or an operational environment before a program can proceed into system development (DUSD(S&T), 2005). Furthermore, the

Deputy Under Secretary of Defense for Acquisition and Technology (DUSD S&T) defines technology readiness assessments, as a "systematic, metrics-based process and accompanying report that assesses the maturity of certain technologies [ ] used in systems" (DUSD(S&T), 2005, pp. 1-2). The requirement listed in the TRA Deskbook is that assessments occur for each increment of the system under the principles of *evolutionary acquisition strategy*. In addition, it suggests that acquisition programs should deliver timely capability to the warfighter even if it requires producing an asset that meets only part of the user's need. The user should resist the urge to demand design solutions that require high-risk requirements (Office of the Assistant Secretary of the Air Force, 2009). We designed our first hypothesis to test the validity of the assumptions surrounding Knowledge Point 1 (Figure 3).

> Hypothesis 1: Defense acquisition programs that do not reach Technology Readiness Level 7 (TRL7) by program initiation (Milestone B) will experience worse program outcomes than defense acquisition programs that do reach TRL7 by program initiation.

Knowledge Point 2: Product Design

The second criteria a program must meet to experience better outcomes is Knowledge Point Two, *KP2*. This Knowledge Point is based on the idea that mature product design will reduce program uncertainty and in turn, increase program success. The GAO reported in 1998 that successful commercial firms had a good understanding of their product's design (90% of Engineering Drawings Complete). Additionally, they posited that a program manager conveys confidence in a product's ability to perform, and the maturity level of the product, by releasing the design drawings to the manufacturer

(GAO, 1998). These design drawings communicate the details of the product and the materials used, as well as how the products piece/parts performed during testing. The heuristic used by both DOD and industry is that the product's design is essentially complete when roughly 90 percent of the engineering drawings are complete. The percent of drawings complete is determined at the Critical Design Review for DOD programs. In 2002, the GAO reiterated, "the most problematic programs…started production before design and manufacturing development work was concluded" (GAO, 2002, p. 24). However, currently the majority of programs do not achieve *KP2* on time. We developed our second hypothesis to test the validity of the assumptions surrounding KP2 (Figure 3).

> Hypothesis 2: Defense acquisition programs that do not complete 90% of their engineering drawings by Critical Design Review will experience worse program outcomes than defense acquisition programs that do complete 90% of their engineering drawings by Critical Design Review.

Knowledge Point 3: Production Maturity

Knowledge Point Three (*KP3*) is the third component that the GAO found critical to the success of commercial firms. To meet *KP3 criteria* a program's production processes must be under "statistical" control (GAO, 2002, p. 13). The leading commercial companies the GAO visited knew that they could produce their products within their quality constraints before they began producing production articles (GAO, 1998). These firms had production processes within statistical control, meaning they were able to produce them within acceptable deviation tolerances. According to the

GAO, programs should meet *KP3* criteria at or prior to the start of production (Milestone C). Currently, the DOD does not require programs to have production processes within statistical control at the Milestone C decision. Production Qualification does not occur until after the Milestone C decision.

Maintaining consistency during the production phase is critical because deviations and defects found after manufacturing a product will cause rework and can increase the cost of each unit. The GAO's *KP3* measurement provides an assessment of the manufacturer's production ability, and meeting it should help prevent rework associated with production process issues. Additionally, since DOD products are manufactured externally, program managers can use *KP3* to monitor the progress of the contractor and subcontractor. We designed our final hypothesis to test the validity of the assumptions surrounding KP3 (Figure 3).

> Hypothesis 3: Defense acquisition programs that do not have manufacturing processes stabilized by Milestone C will experience worse program outcomes than defense acquisition programs that do have their manufacturing processes stabilized by Milestone C.

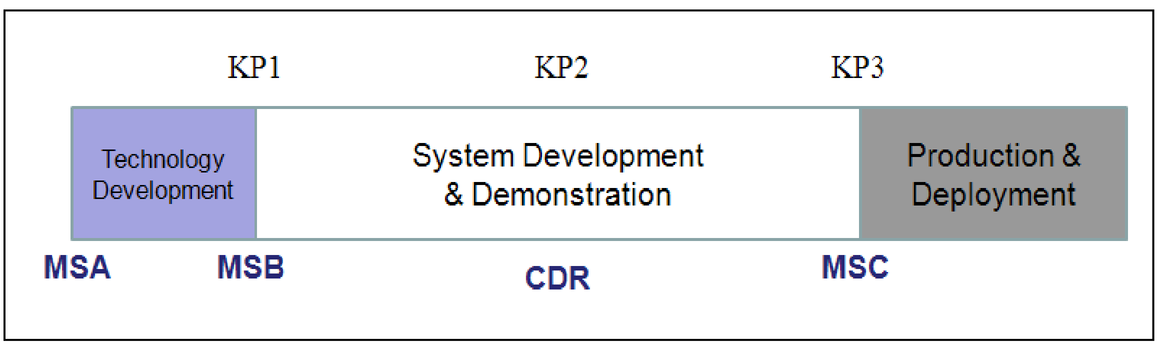


Figure 3: Knowledge Point Schedule

Current Acquisition Reform

In late 2005, the GAO conveyed its continuing concerns about the DOD's management of its investment portfolio to the U.S. Senate. The GAO's concern was that acquisition program cost increases, combined with operations in Iraq and Afghanistan will prohibit the military from delivering assets essential to the warfighter (GAO, 2005). Further, they said that the DOD knows what to do to garner more successful acquisition outcomes but that it is not implementing the controls necessary to initiate the change (GAO, 2005). In addition, the GAO was concerned that the typical margin of error in percentage terms will equate to significant cost overruns as the acquisition portfolio grows in value. According to GAO, in a mere five years (2001 to 2006) the Total Cost of the DOD's top five acquisition programs grew from $291 Billion Dollars to approximately $550 Billion Dollars as shown in their table, reproduced below (Table 1).

Table 1: Total Cost of DOD's Top 5 Programs (FY06 Dollars)

2001		2006	
Program	**Cost**	**Program**	**Cost**
F/A-22 Raptor Aircraft	$65.0 billion	Joint Strike Fighter	$206.3 billion
DDG-51 class destroyer ship	$64.4 billion	Future Combat Systems	$127.5 billion
Virginia class submarine	$62.1 billion	Virginia class submarine	$80.4 billion
C-17 Globemaster airlift aircraft	$51.1 billion	DDG-51 class destroyer ship	$70.4 billion
F/A-18E/F Super Hornet fighter Aircraft	$48.2 billion	F/A-22 Raptor aircraft	$65.4 billion
Total	$290.8 billion	**Total**	$550.0 billion

(Adapted from (GAO, 2005, p. 3))

Weapon System Reform Act of 2009

GAO's *KAT* has influenced the acquisition community for the past ten years, most recently affecting the policy enacted in the 2009 Weapon Systems Acquisition Reform Act (111-23, 2009). Recent changes in DOD acquisitions essentially direct the DOD acquisition community to implement the *KAT* approach. On May 22, 2009 the 111th Congress passed the *Weapon Systems Acquisition Reform Act of 2009 - Public Law 111-23*, to improve the DOD acquisition environment. This Act specifically prescribes changes to acquisitions through three general categories: (1) The Acquisition Organization, (2) Acquisition Policy, and (3) Additional Acquisition Provisions. This Reform Act seems to be consistent with the GAO's *KAT*, it generally supported the GAO's claim that following the *KAT* would produce better program outcomes.

First, Section 103 of the Act, *Performance Assessments and Root Cause Analysis for Major Defense Acquisition Programs*, states that the Secretary of Defense must designate a senior official who will conduct performance assessments and root cause analysis for MDAPs ((111-23, 2009)). In other words, they will investigate MDAPs that miss one or more key performance parameters to determine why they missed the parameter. The person in this position will be responsible for the performance assessments of MDAPs on a periodic and an as needed basis. They will conduct root cause analyses of MDAPs as well as issue the policy and guidance needed to govern the process of performing these root cause analyses. This analysis should yield an evaluation of the usefulness of the current metrics used to assess program performance and,

recommend any necessary changes to the metrics. Lastly, this position will advise acquisition officials on potential program performance issues.

Again, the purpose of the Root Cause Analysis is to assess the underlying cause of a programs inability to meet one or more key performance parameters (PL111-13). The parameters include cost, schedule, and performance as well as the following eight additional parameters:

I. Unrealistic performance expectations
II. Unrealistic baseline estimates for cost or schedule
III. Immature Technology or excessive manufacturing or integration risk
IV. Changes in Procurement Quantities
V. Inadequate program funding or funding Instability
VI. Poor Performance by Government or Contractor Personnel responsible for program management
VII. Any other Matters

Of particular significance in the context of this study, is item III from the list, *Immature Technology or excessive manufacturing or integration risk.* The 2009 GAO report found that of the 39 programs that provided them with data only 14 had, or would have, mature technology at or prior to Milestone B (GAO 2009, pg 16). We expect that if having mature technology at MSB does provide better program outcomes then the root cause analysis will substantiate the GAO's claim.

Section 104 of Public Law 111-23 requires the Directors of Defense Research and Engineering and Developmental Test and Evaluation to submit a report of technology maturity and integration risk to the Secretary of Defense annually. This change is consistent with the GAO's KAT, specifically KP1 (technology maturity level). This

section requires that the Director of Defense Research and Engineering develop and publish knowledge-based technology maturity standards for MDAPs. It requires that technology maturity assessments occur at key stages in the acquisition process. We expect that since H.R. 2101 amended Title 10 moving the Preliminary Design Review process prior to the Milestone B decision, that the technology maturity measurement will also happen prior to Milestone B.

In the 1980's acquisition reform focused on fraud, waste, and abuse. The Packard Commission altered that trajectory to a focus on increasing the efficiency and effectiveness of DOD acquisitions. Nevertheless, DOD acquisition programs still suffer from cost and schedule overruns. We hope that through our assessment of the KAT we can determine if programs that met the KP criteria as outlined by the GAO experienced better program outcomes than programs that did not. We anticipate that the results of our analysis will help DOD program managers better understand the effectiveness of the *KAT*.

Chapter III: Data Collection and Methodology

Data Source and Variables

We used acquisition program performance information for our analysis. We collected this information from assessments that the Government Accountability Office conducted and published. These reports documented acquisition-program performance characteristics for high profile and large budget acquisition programs (GAO, 2008, p. 3). The GAO performed these studies and published their reports annually from Calendar Year 2003 through Calendar Year 2009, with each report covering an average of 55 programs.   We conducted approximately twenty random data point verifications to validate the accuracy of our data.

We used the most recent iteration of each program found in the GAO reports for our analysis. We used only the most current instance of each program to minimize the intercorrelation of our predictor variables (Kutner, Nachtsheim, Neter, & Li, 2004, p. 279). This yielded a sample size of 107 acquisition programs. Unfortunately, not all programs had all of the appropriate data reducing the sample size further for some of our tests. For example, there were 90 programs with complete data for *KP1*, 71 programs with complete data for *KP2*, and 51 programs with complete data for *KP3*. Furthermore, of the programs with complete data, only 11 programs had met the *KP1* criteria, only 15 had met *KP2* criteria, and only 4 programs had met *KP3* criteria.

We used the program performance data that were contained in the GAO reports to test our hypotheses. To recap, the GAO's claim is that if a program meets the

knowledge-point (*KP*) criteria at the predetermined junctures, the program will experience better results than programs that did not meet the *KP* criteria. We considered the knowledge points "treatments," and compared the outcomes of the programs that met the *KP* criteria with those that did not. We expected to find cost and schedule increases to be smaller for programs that met the *KP* criteria, and we expected to find a smaller reduction in the number of units produced for programs that met the *KP* criteria.

$$\boldsymbol{Ho}: \boldsymbol{\mu\ outcome\ of\ Group\ 0\ \geq \mu\ outcome\ of\ Group\ 1}$$
$$\mathbf{Ha}: \boldsymbol{\mu\ outcome\ of\ Group\ 0\ < \mu\ outcome\ of\ Group\ 1}$$

- *Where Group 0 did not meet KP criteria and Group 1 Met KP criteria*
- *DVs/Outcomes measured: QCP*

$$\boldsymbol{Ho}: \boldsymbol{\mu\ outcome\ of\ Group\ 0\ \leq \mu\ outcome\ of\ Group\ 1}$$
$$\mathbf{Ha}: \boldsymbol{\mu\ outcome\ of\ Group\ 0\ > \mu\ outcome\ of\ Group\ 1}$$

- *Where Group 0 did not meet KP criteria and Group 1 Met KP criteria*
- *DVs/Outcomes measured: UCC, TCC, RDCC, SIP, PCC*

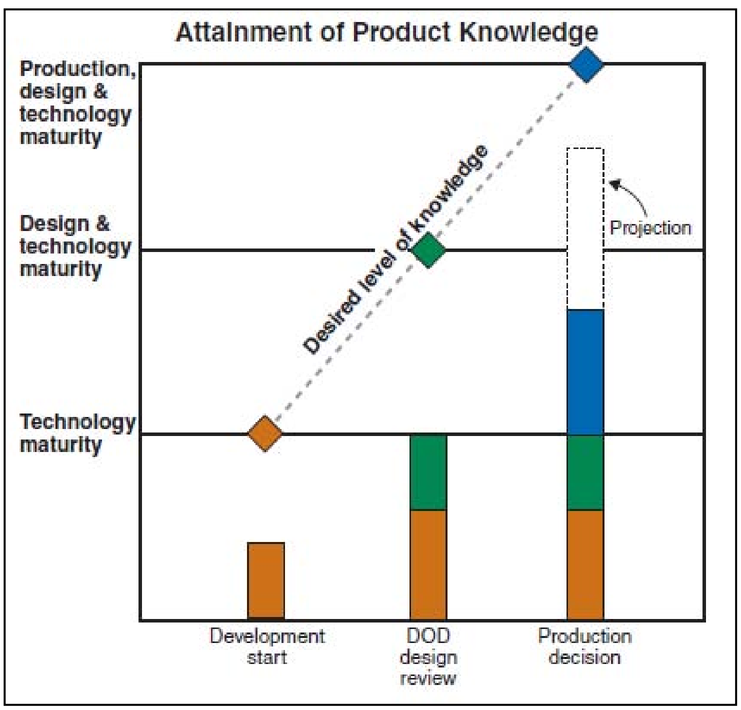


Figure 4: Knowledge Point Attainment (GAO 2008)

The GAO measured whether or not a program met *KP1*, *KP2*, and *KP3* criteria at the *KAT's* predetermined knowledge points (Figure 4) in each report. We used these *KP1*, *KP2*, and *KP3* measurements as our independent variables. We gave each independent variable an indicator of "0" if the program did not meet the KAT criteria on time and gave a "1" to programs that did meet the KAT criteria on time.

Limitations of the Data

There are many factors external to the program office that can affect program outcomes. For instance, unexpected changes to program requirements, volatile funding sources, and unexpected schedule changes due to factors beyond the control of the program office can disrupt program performance outcomes (GAO, Weapons Acquisition: A Rare Opportunity for Lasting Change, 1992). These external factors may limit the explanatory power of our models since they focused solely on whether a program met the KP criteria (Deloitte Consulting LLP, 2008; Kutner, Nachtsheim, Neter, & Li, 2004, p. 74).

Our sample size of 107 programs was generally enough to assess whether a statistically significant relationship existed between programs that met the *KP* criteria versus those that did not (Kutner, Nachtsheim, Neter, & Li, 2004). However, many programs have not met the *KP* criteria on time. This limited the generalizeability of our findings for other programs since such a small sample could contain atypical program outcomes relative to the general program population (Trochim & Donnelly, 2008, p. 36).

In addition, we have many more data points for *KP1* than for *KP2 or KP3* due to the time series nature of our data. Many programs were not far enough along to have a measurement for *KP2* or *KP3.* The disparity in our data was reason for us to conduct independent *KP* analysis so we could leverage the data points. If we had analyzed the *KP*'s in combination, we would have eliminated many data points due to missing data.

In a few circumstances, we made assumptions based on the data available. Some program assessments lacked information about whether a program met a given *KP* on time. However, these reports did assess the programs current *KP* status. If a program did not meet a *KP* as of the report date, and the report date was post *KP* measurement, we assumed the program had not met the preceding *KP* criteria on time. Figure 5 exhibits this scenario. This program did not have the data available regarding *KP1*, but it is reasonable to assume that since they had not met the criteria in 2007 that they had not met the criteria in 1995.

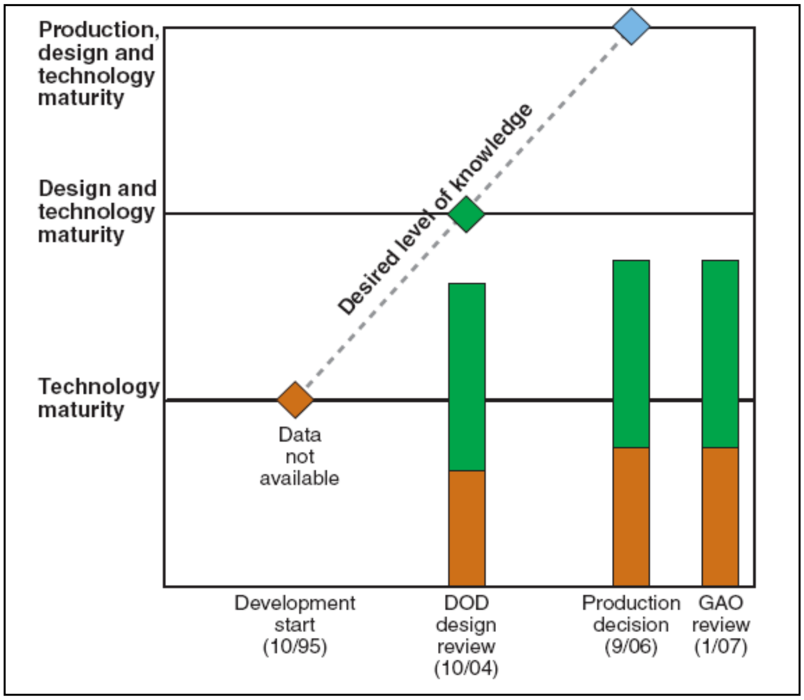


Figure 5: Data Deduction   (GAO, 2008, p. 27)

The GAO did not randomly select the acquisition programs they followed (Trochim & Donnelly, 2008, p. 38). However, our dataset contains a good mixture of the different program types (Table 2). We consider these programs to be a good representation of DOD acquisition programs and represent the environment in which the GAO expects the *KAT* to apply.

Table 2: Data Demographics

	Number of Programs	Percent of Dataset
Air	33	31%
Space	15	14%
Munition	11	10%
Sea	15	14%
Missile	16	15%
MAIS	14	13%
Land	2	2%
Space/Air	1	1%

Dependent Variables

We collected the dependent variable (DV) information from the same GAO reports that contained our independent variables. The information we gathered measured specific program performance parameters such as schedule, cost and quantity change. Since the GAO's *KAT* associates *KP* completion with better acquisition program outcomes, these variables provided a way for us to measure program performance. The performance measures we used were Quantity Change Percent (*QCP*), Unit Cost Change

(*UCC*), Total Cost Change (*TCC*), R&D Cost Change (*RDCC*), Schedule Increase Percentage (*SIP*), and Procurement Cost Change (*PCC*) (Figure 6).

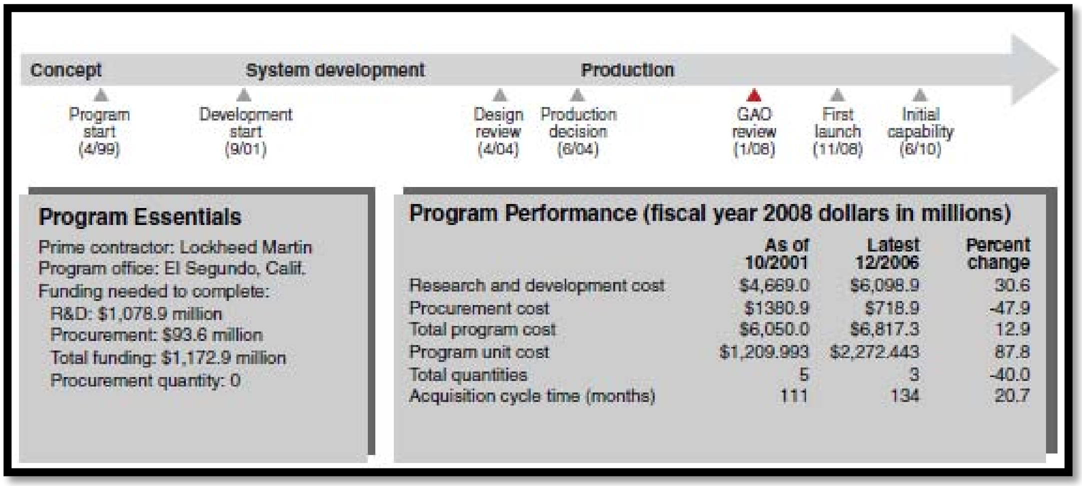


Figure 6: Program Performance with Respect to Program Baseline (GAO, 2008)

As previously mentioned, the GAO claimed that programs that met the *KAT* criteria would experience better acquisition outcomes than programs that did not. Since program sizes vary, we controlled for program size by using percentages. We expect better performance to be evident through smaller percentage increases from a programs baseline. We defined a *better acquisition outcome* to mean an outcome in which a program performs at or below its program baseline, or to mean better performance with respect to those programs that did not meet the KP criteria.

Dependent Variable Description

The first Dependent Variable (Table 3) we used was Schedule Increase Percent (SIP), this variable measured program schedule change with respect to a program's baseline. To test the *KAT* claim, we tested whether programs that met the *KP* criteria

performed better than those programs that did not meet the *KP* criteria. Better performance would be indicated by a smaller percent schedule change.

The next Dependent Variable we used was *Quantity Change Percent* (*QCP).* This variable measured the percentage change in a program's anticipated production quantity relative to the number the program expected to produce at its baseline date. We reasoned that managers at risk of exceeding their budgets might need to reduce their production quantities in order to stay within budget. Therefore, we expect that for this variable, smaller quantity reductions indicate better program outcomes. The exception to this would be if quantities increased due to mission need, regardless of poor unit cost performance. We had 19 programs in our dataset that had not met any *KP* criteria they were accountable for, but had an increase in *QCP* nevertheless. Of these programs, there were ten programs that missed the *KP* criteria and experienced significant unit cost growth, and yet these programs increased the number of units they produced. This behavior leads us to question the degree to which QCP is a good metric for "good" acquisition programs. Consequently, we rely less on this variable than some of our other variables which we think are more highly correlated with successful acquisition programs.

In addition to quantity change, we looked at the change in unit cost, *UCC.* We tested to see if programs that met the *KP* criteria had a smaller unit cost percent change than programs that did not meet the *KP* criteria. We collected all unit cost change amounts in percent change relative to their estimated cost on the program baseline date.

We also looked at Total Program Cost Change, *TCC,* to determine if a program's total cost change was smaller for programs that met the *KP* criteria than for programs that

did not. Since the three *KP's* focus on different types of knowledge and are at different points in the program lifecycle, it is reasonable to assume that they may affect particular components of a program more than others. *TCC* should allow us to see the total financial effect the *KPs* have on a program as opposed to growth in one particular area.

Procurement Unit Cost is the cost to purchase a unit (its piece/parts and assembly cost) whereas a program's unit cost is unit cost as a function of total program costs (Total cost/number of units). We used the Procurement Unit Cost Change, *PCC,* to determine if programs that met the *KP* criteria had a smaller increase in procurement costs relative to programs that did not meet the *KP* criteria.

Our last variable, Research and Development Cost Change, *RDCC*, measured a program's R&D cost change in percentage terms. We expected that programs that did not have mature technology and an understanding of product design would experience research and development cost growth.

The GAO's *KAT* states that programs that meet the *KP* criteria on time will experience better outcomes. We used the variables *UCC, PCC, TCC, RDCC, SIP, and QCP* as our measures of program performance.

The GAO described the *KAT* as a sequential process and that in order to meet either *KP2* or *KP3* a program would need to have met the preceding *KP(s)* (GAO, 2004, pp. 4-5). It is reasonable to assume that a program will be more likely to achieve either *KP2* or *KP3* if it has achieved the *KPs* that precede it. However, we found that eleven programs in the reports had met *KP2* criteria without meeting *KP1* criteria. In addition, since each *KP* was measured using criteria unique to that *KP* and because each *KP* measurement is independent of the other *KPs*, we examined each *KP* individually.

Methodology

The primary purpose of our study was to test the GAO's KAT by determining if a difference existed between the outcomes of two groups, those that have met KP criteria and those that have not. We compared programs that met *KP1, KP2, and KP3* with programs that did not to see if programs that met the criteria performed better. We conducted Independent-Sample T-Tests to determine if the mean performance of the programs that met the *KP* criteria was better than the mean performance of the programs that did not (Kutner, Nachtsheim, Neter, & Li, 2004, pp. 1309-1310). We used this methodology instead of an ANOVA because our research question involves one-way or directional hypotheses, which indicate that *F* tests are inappropriate. T-Tests are an appropriate method for determining if the mean of the group that failed to meet *KP1* (coded as KP1=0) is "worse" than the mean of the group that achieved *KP1*, where "worse" may be greater or lesser depending on the particular metric (Kutner, Nachtsheim, Neter, & Li, 2004, p. 1310).

Our primary statistical test was the standard T test with pooled variance (Bulmer, 1979, pp. 145-154; McClave, Benson, & Sincich, 2008). One of the assumptions of this test is that both groups have the same variance. To test this assumption we conducted the Levene Test and examined the corresponding P-Value (McClave, Benson, & Sincich, 2008, p. 455). In cases where this P-value was less than 0.05, we concluded that the variances were statistically different and consequently the standard T test was inappropriate. In these cases, we instead used the Welch Test since it accounts for different variances between the groups (Montgomery, 1999, p. 392). In either case

(standard T test or Welch test), we examined the resulting P-value to find significant relationships.

Table 3: Variable List

	Description	**Nomenclature**
Dependent Variables		
Schedule Increase Percent	Measured the schedule increase relative to the Program's Baseline Date (Percentage)	*SIP*
Quantity Change Percent	Measured an increase/decrease in production units relative to the Program's Baseline Date (Percentage)	*QCP*
Unit Cost Change Percent	Measured the change in cost of each production unit relative to the Program's Baseline Date (Percentage)	*UCC*
Total Cost Change Percent	Measured the change in the total cost of a program relative to the Program's Baseline Date (Percentage)	*TCC*
Procurement Cost Change Percent	Measured the change in Procurement Costs relative to the Program's Baseline Date (Percentage)	*PCC*
Research & Development Cost Change	Measured the change in Research and Development costs relative to the Program's Baseline Date (Percentage)	*RDCC*
Independent Variables		
Knowledge Point 1	Measured whether a program had mature technology (Technology Readiness Level 7) by program initiation (Milestone B)	*KP1*
Knowledge Point 2	Measured whether a program had 90% of its engineering drawings by Critical Design Review	*KP2*
Knowledge Point 3	Measured whether a program's manufacturing processes were in statistical control by Milestone C	*KP3*

Distribution of Variables

In addition to testing the relationships between meeting *KP* criteria and program performance, we looked at the distribution of our variables. We visually examined the distribution to see if programs that met the *KP* criteria experienced a more tightly distributed range of outcomes than programs that did not meet. In other words, though programs may not have different mean outcomes with respect to meeting *KP* criteria, programs that meet the *KP* criteria may have a smaller deviation from the mean than programs that did not meet the *KP* criteria (Figures 8 - 10).

Finally, we looked at the effects of the *KAT* on programs by type of program. For example, we wanted to see if a program's product had any correlation to whether it met the *KP* criteria or if the *KAT* was more effective on certain types of products. Our sample size was too small for statistical analysis so we conducted a visual analysis of the data for this measurement.

Controlling for Program Age

We supplemented our t-tests with an additional model to see if a program's age influenced our results. One of the features of our data is that GAO's program performance measurements occurred at different points in the program's lifecycles. For example, the GAO measured some programs shortly after the program reached a *Knowledge Point*, while in other cases, the GAO's measurement occurred many years after a program had reached a *Knowledge Point.* This meant that some programs had much more time to incur cost, schedule, and quantity change than other programs and

consequently, we concluded that by adding *AGE* into our model we could control for these differences and increase the fidelity of the relationships.

We used the program initiation date (Milestone B) and the date of the GAO's measurement to determine the approximate number of days a program had existed (*AGE)*. We then retested our hypothesis using linear regression models in lieu of t-tests to accommodate our control variable. The model chosen was a straightforward bivariate regression model of the form:

$$Y = \beta_0 + \beta_1 KP + \beta_2 AGE + \epsilon_i$$

Y Variables: UCC, QCP, PCC, SIP, TCC, RDCC; Error Term: ϵ_i

In the course of fitting these regression models, we conducted reasonable regression diagnostics in order to check the assumptions of ordinary least-squares (OLS) regression, which is zero-mean, independent, constant variance error terms, as well as checks for multicolinearity and influential points (Kutner, Nachtsheim, Neter, & Li, 2004, pp. 102-103). The results of these diagnostics implied non-constant variance, so in response we utilized the standard technique of transforming the Y variable $(\text{Kutner}, \text{Nachtsheim}, \text{Neter}, \& \ Li, 2004, pp. 132 - 137)$. In most cases, a simple natural logarithm transform was sufficient to remedy the non-constant variance, although for RDDC and TCC, Box-Cox analysis showed that a power transform with $\lambda = -1.4$ appeared more appropriate. In all cases, we were able to develop a model that appeared to satisfy the assumptions of OLS.

Chapter IV: Analysis and Results

Table 4 provides the descriptive statistics of our variables. We found that missing the *KP* criteria did not have a pervasive impact on our dependent variables. Some dependent variables showed improvement when programs met the *KPs*, but most dependent variables did not. However, we were still able to find some important relationships between programs meeting the *KP*'s and better program performance. Additionally, we assessed whether program type had an effect on a program's performance or a program's likeliness to meet the *KP* criteria. We could not test our conclusions statistically, but still found the results relevant to this study.

Test of Hypotheses

The results of our analyses are in Table 5. Through our analysis of these programs, we found a few significant relationships. First, we found that *Research and Development Cost Change* related closely to *KP1*. Programs that had mature technology at or prior to Milestone B had a smaller increase in Research and Development costs than programs that had immature technology at Milestone B. This confirms our expectation that *RDCC* is a good measure of program performance, specifically, with respect to *KP1*. Furthermore, we presume that programs with immature technology have a higher rate of Research and Development funding cost growth since technology maturation must occur as the program moves past Milestone B.

Table 4: Descriptive Statistics (one-tailed)

Correlation Matrix

		Mean	STDV	1	2	3	4	5	6	7	8	9
1. KP1	Pearson Correlation			1.00	.961**	.946**	-0.07	.293**	-0.20	-0.09	-0.17	-0.05
	Sig. (1-tailed)		1.19		0.00	0.00	0.30	0.01	0.05	0.24	0.07	0.34
	N			91	69	42	54	67	65	72	73	65
2. KP2	Pearson Correlation				1.00	.948**	-0.01	.237*	-0.21	-0.13	-0.17	-0.09
	Sig. (1-tailed)		1.79			0.00	0.47	0.04	0.07	0.17	0.10	0.26
	N				72	42	44	55	54	59	59	53
3. KP3	Pearson Correlation					1.00	-0.15	.385**	-.258*	-0.06	-0.04	-0.09
	Sig. (1-tailed)		0.61				0.20	0.01	0.05	0.36	0.39	0.29
	N					52	34	43	42	44	44	40
4. SIP	Pearson Correlation						1.00	0.10	.523**	.331**	.337**	.242*
	Sig. (1-tailed)	0.29	0.50					0.22	0.00	0.00	0.00	0.02
	N						67	66	66	67	67	66
5. QCP	Pearson Correlation							1.00	-.268**	.542**	.481**	.867**
	Sig. (1-tailed)	0.26	1.51						0.01	0.00	0.00	0.00
	N							81	79	81	81	78
6. UCC	Pearson Correlation								1.00	0.14	0.10	0.00
	Sig. (1-tailed)	0.48	0.95							0.10	0.18	0.49
	N								79	79	79	76
7. TCC	Pearson Correlation									1.00	.822**	.954**
	Sig. (1-tailed)	0.52	1.17								0.00	0.00
	N									86	86	79
8. RDCC	Pearson Correlation										1.00	.716**
	Sig. (1-tailed)	0.98	4.16									0.00
	N										87	79
9. PCC	Pearson Correlation											1.00
	Sig. (1-tailed)	0.53	1.27									
	N											79

**. Correlation is significant at the 0.01 level (1-tailed).
*. Correlation is significant at the 0.05 level (1-tailed).

In addition to *RDCC,* we found that the Unit Cost Change (*UCC)* for programs that did not meet the *KP* criteria increased more than for those programs that met the *KP* criteria. In retrospect, we find that *UCC* is an important variable since the cost of each unit is a function of several other variables (Figure 7). We find *UCC* to be more important than any other variable because it is affected when any cost or quantity variable changes. *Unit Cost Change* is a sensitive variable encompassing many program changes. Our finding was confirmed given that this variable had a significant relationship with more independent variables than any other dependent variable. We found that *KP1*, and *KP3*, related closely to *Unit Cost Change* and that *KP2* had a tenuous relationship.

Lastly, we could not prove that if a program met the *KP* criteria it would experience a smaller schedule increase than if it did not meet the *KP* criteria. This finding was interesting, because it seems counterintuitive. We expected to find that programs that missed the *KP* criteria would experience larger schedule increases than programs that met the *KP* criteria. Specifically, we expected programs that missed *KP1* or *KP2* to have larger schedule increases since still needed to mature their technologies and complete their product designs.

$$\text{Unit Cost} = \frac{Total\ Program\ Cost\ *}{Total\ Quantities}$$

$$*\,Total\ Program\ Cost = Research\ and\ Development\ Cost + Procurement\ Cost$$

Figure 7: Unit Cost Function

Table 5: Results of Analyses

	Hypothesis 1 *(KP1)*	**Hypotheses 2** *(KP2)*	**Hypothesis 3** *(KP3)*
SIP	0.298	0.468	0.197
QCP	0.145†	0.180†	0.205†
UCC	0.054*	0.066*	0.049**
TCC	0.236	0.172	0.360
RDCC	0.001**†	0.104	0.390
PCC	0.339	0.256	0.294
* < .1 ** <.05 *** <.01		†Welch Test: Unequal Variances	

The results of our t-tests indicate that if a program manager adheres to the *KAT* they will reduce their unit cost growth. As mentioned earlier we did not find significance with many variables. However, we believe that we could not find significance with *PCC, TCC, SIP,* and *QCP* because of the inherent variability of acquisition programs, with other uncontrolled factors making a true effect. . Nevertheless, we found *UCC* to be the most important variable for determining *better program performance.* Unit Cost changes when any of the other variables change. Furthermore, we propose that *UCC* is a better measurement of program performance because of this transparency and because it can be easily compared among programs of different types. For example, a satellite program

may have a large R&D cost relative to its Procurement costs while a dumb munition that is mass-produced, may have a much larger Procurement cost relative to its R&D costs. This can make R&D or Procurement cost growth hard to compare among programs.

Decreased Variability

In most cases, the cost, schedule, and quantity change for programs that met the KAT criteria varied less than for programs that did not. Figure 8 through Figure 10 show the range of outcomes for each variable with respect to the *Knowledge Points* (0 = Missed KP; 1 = Met KP). In many cases, programs did not experience better results by meeting the *KP* criteria. However, some programs that met the *KP* criteria appeared to experience decreased variability. A double-asterisk, in the following figures, indicates the groups with statistically different variances according to the results of the Levene test for equal variance. This decrease in variability may be significant because inspection of the data seems to suggest that the distribution of outcomes has a heavy tail in the negative (or "bad") direction. Thus, meeting *KP* criteria might reduce the probability of a program performing *really* badly.

Controlling for Program Age

Table 6 displays the results of our alternative model, which controlled for program age. First, we found that the relationship between *RDCC* and *KP1* weakened. We did not find that programs that missed *KP1* experienced higher Research and Development Costs when we controlled for age. However, we found a marginal

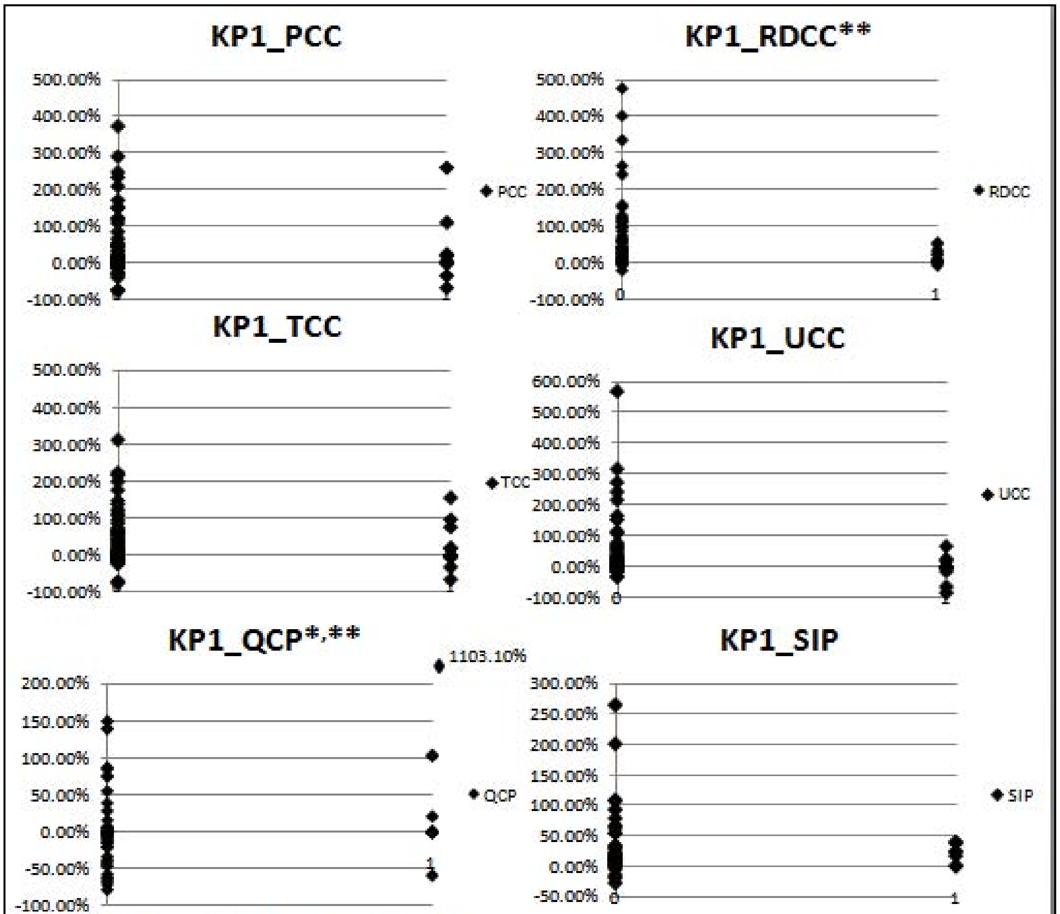
relationship between Research and Development Cost increases and programs that missed *KP2*. While we cannot explain this with certainty why this occurs, we do note that *KP2* measurement involves a near complete product design, and hence it makes sense that programs that did not have a clear understanding of their product as they approached production experienced more cost growth. This could also explain why KP1 was not significant after we controlled for age. Milestone B could be too early in the acquisition cycle to be a reliable estimate of R&D cost growth. Programs that meet KP1 criteria may begin with an advantage, but it may be that the advantage dissipates with time due to factors exogenous to the program office.

Table 6: Results of Analysis, Controlling for Age

	KP1	*KP2*	*KP3*
SIP	0.490	0.239	0.485
QCP	0.016**	0.105**	0.028**
UCC	0.003***	0.011**	0.022**
TCC	0.233	0.159	0.384
RDCC	0.135	0.096*	0.282
PCC	0.337	0.192	0.289

* < .1
** <.05
*** <.01

Second, we found that the relationship between programs that met the *KP* criteria and lower unit cost growth increased substantially. Our previous tests indicated a marginal relationship, but when we controlled for *AGE* the relationship became significant for all of the independent variables. Furthermore, Quantity change became significant with respect to *KP1* and *KP2*. In other words, programs that met *KP1* and *KP2* experienced a smaller reduction in quantities than programs that did not meet these *Knowledge Points.* Naturally, programs have more opportunity to experience cost and schedule changes as they age. By controlling for age, we were able to account for this artifact and get a clearer understanding of how the KP criteria relate to unit cost and quantity change. In other words, we could determine if the cost and quantity changes correlated to meeting the *Knowledge-Points*, and we could eliminate the possibility that those relationships were simply a function of a program's age.



*We expect a negative *QCP* to indicate poor performance
** Indicates the variance of the two groups was statistically different

Figure 8: KP1 versus DV's

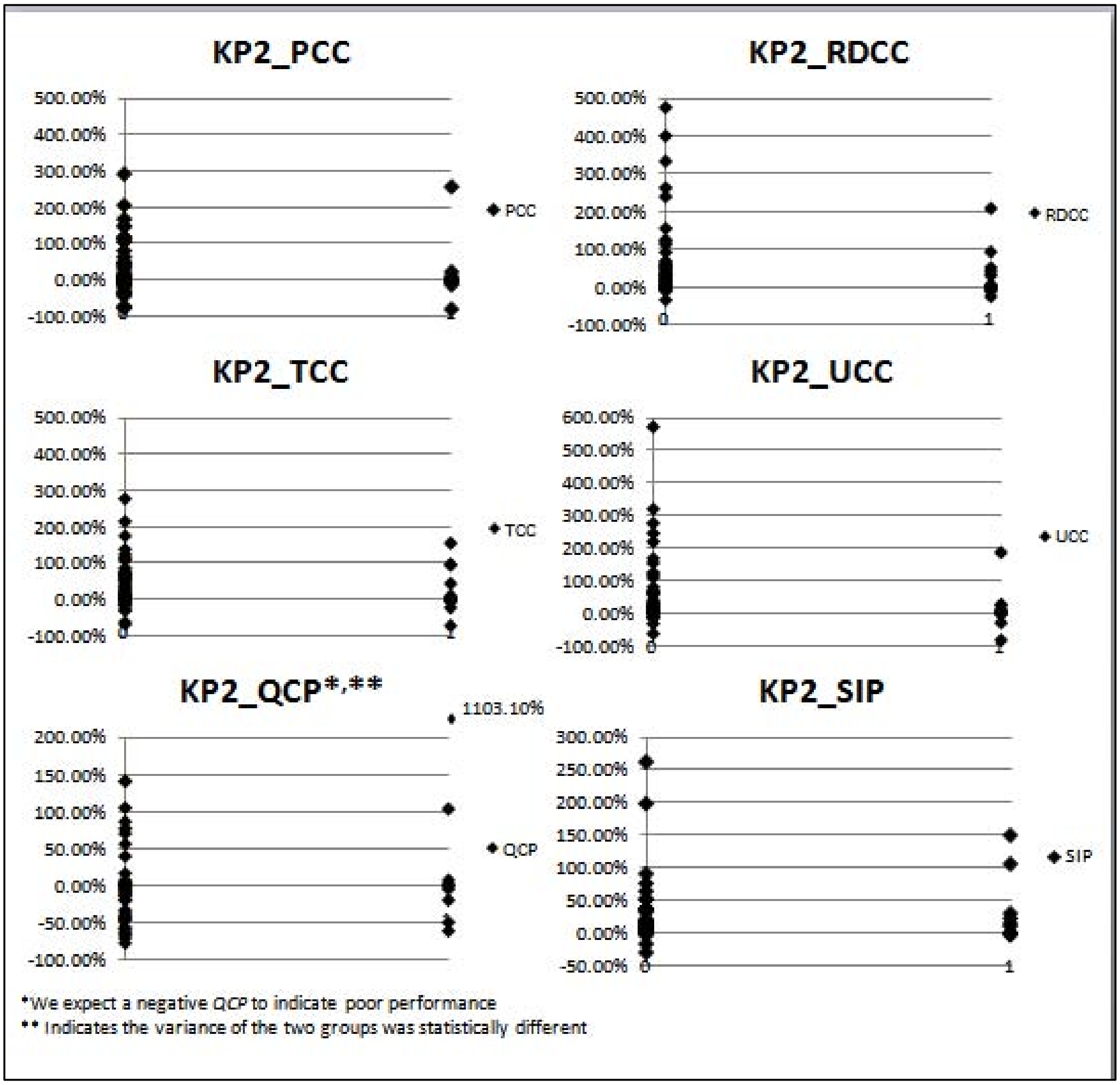


Figure 9: KP2 versus DV's

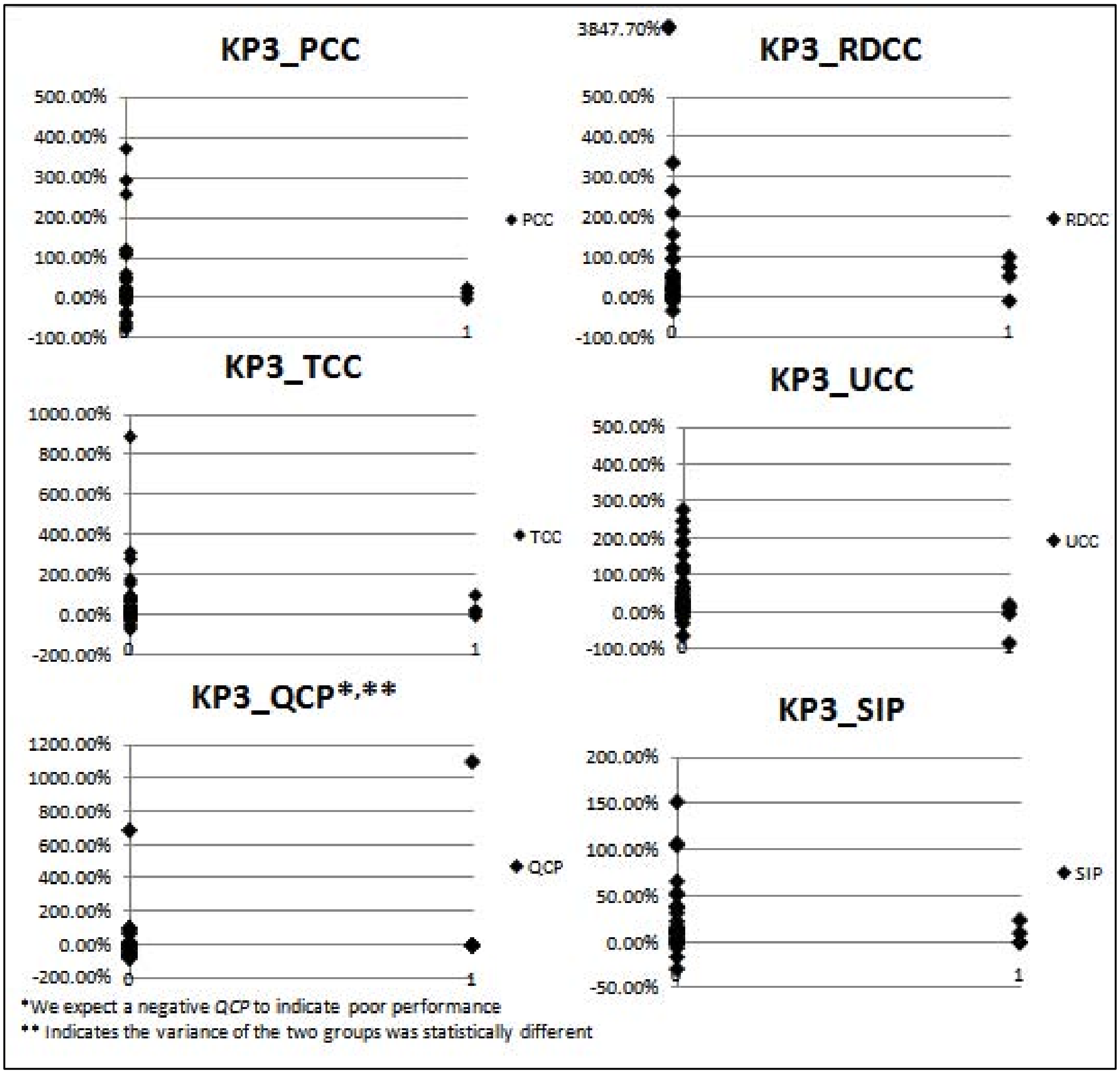


Figure 10: KP3 versus DV's

Next, we organized the programs in our dataset into categories. We looked to see if any trends existed among the program types. Two program types, *Land* and *Space/Air*, contained only one data point so we could not obtain any trends from those groups. Of the groups we could assess, we found that Munition programs were much more likely to meet *KP1* criteria than any other program type. Additionally, we found that Space programs and Missile programs met *KP2* criteria more than any other program type. We found that *KP3* was the most frequently missed *KP;* only 7.8% of the programs assessed at *KP3* had production processes in statistical control.

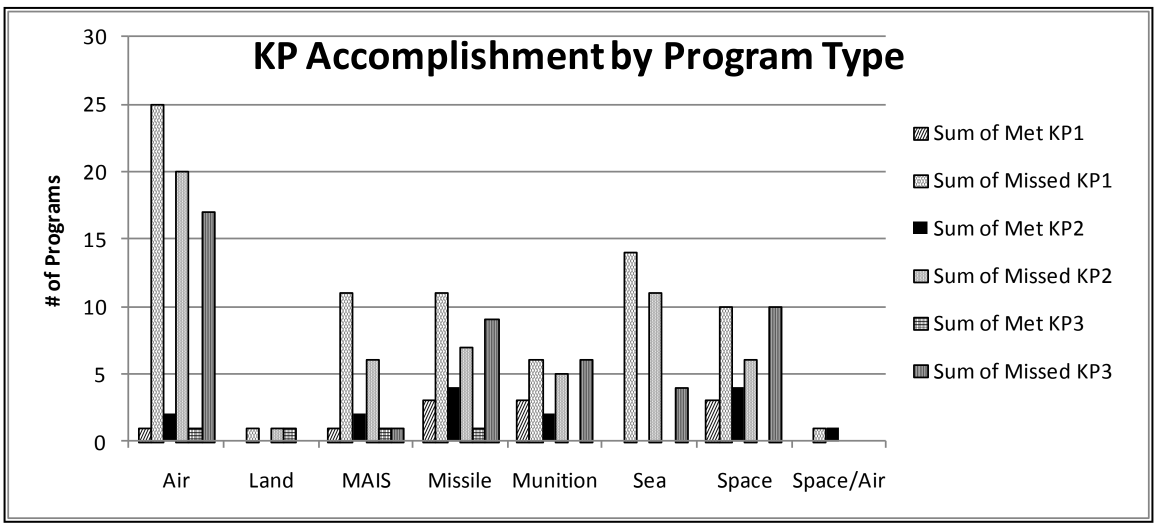


Figure 11: KP accomplishment by program type

Lastly, we analyzed whether the *KAT* was more influential on one program type than another was (Appendix B). We expected that meeting the *KP* criteria would have a smaller affect on certain program types for a couple of reasons. First, the outcomes of

high profile programs may be influenced more by politically driven decisions than by program execution decisions. Second, simpler programs may have fewer uncertainties remaining after *KP* completion providing for a better chance at *improved* outcomes. Our sample size was reduced significantly when we categorized our variables by program type. This limited the conclusions we could draw from the data. The output of our analysis is in Appendix B. Generally, all program types appeared to be affected relatively similarly. However, because there are more data points for programs missing the *KP* criteria than meeting the criteria we could not make any certain claims. The decreased variability and better outcomes may have been due to chance, or may have been an artifact of the smaller sample size.

Lastly, it is important to note that the programs that met the *KPs* had certain characteristics in common. For instance, not many Air programs met the *Knowledge-Points.* However, Air programs that met the *KPs* were older programs that were being upgraded, or in the case of the Light Utility Helicopter, a commercial-of-the-shelf product. Furthermore, we found that the preponderance of programs that met the *Knowledge-Points* were in either the missile or munition category. These programs are by no means simple, however they are much less complicated than an Airframe or Space system.

Chapter V: Conclusions

The GAO has championed the *Knowledge-Based Acquisition Theory* for years. Their claim has been that when programs have mature technology, a complete product design, and mature production processes, they will experience better results. Our thesis focused on validating the GAO's claim in order to further the acquisition community of practice. In many ways, our study validated the GAO's claim. However, we also found that the *KAT* is not a comprehensive means to program success. There are other factors not captured in the *KAT* that contribute to program success.

We could not find a significant relationship between *KP1, KP2, or KP3,* and *PCC, SIP*, or *TCC* performance. We believe that this is because acquisition programs are unique and will not all be affected the same when a program misses *KP1, KP2, or KP3* criteria. However, we did observe that when a program missed the *KP* criteria its outcome varied much more wildly than programs that had met the *KP* criteria.

Additionally, we observed that the *KAT* correlated considerably with improved unit cost change performance. In retrospect, we believe that the *UCC* variable is the most suitable measurement of success of all the variables because it encompasses several program measurement components. Unit cost changes in any program when either a dollar or a quantity component changes (unless cost and quantity change proportionately). Furthermore, since *UCC* was a significant variable for all *KP's* with the alternative model, we feel its correlation validated the GAO's *KAT* as an effective approach for better program outcomes.

Limitations

Some limitations of our study warrant future research. First, our sample size was limited. As of this study, the GAO had only been tracking *KP* achievement for seven years (2003 – 2009) limiting our analysis to a combined 107 programs, and some of these programs had only partial data. To date, relatively few programs have met the *KP* criteria, giving us unequal sample sizes. More programs missed the *KP* criteria than met them. Additionally, we had fewer data points for *KP2* than for *KP1,* similarly, we had fewer data points for *KP3* than for *KP2.* Our dataset only contained four programs that met *KP3* criteria preventing us from conducting a rigorous analysis of the correlation between *KP3* criteria and better program outcomes. This study would benefit from a retest of the hypothesis when more data points are available.

There were limitations to the conclusions we made. We did not have the right kind of data (e.g. experimental) to test for causality. Future researchers can use both the data provided by the GAO and annual program data from the Selected Acquisition Reports to see if program cost and schedule performance was altered once a program met the *KP* criteria. In addition, we could only show that program outcomes were in general correlated to the *KP* criteria. We could not determine if certain types of programs were more strongly correlated than others. A larger sample of programs may show that the *KAT* is only applicable to specific program types.

Lastly, while it appears that programs have been reluctant to adopt the GAO's *Knowledge-Based Approach*, it may be that the approach must be adapted to the DOD acquisition environment. Department of Defense programs are by nature innovative and cutting edge, thus bearing a higher degree of uncertainty and risk than commercial

programs (Friedman, 2009). The DOD program managers are often not afforded the time and resources needed to obtain the same knowledge of their program as commercial program managers. It may be unjust to compare DOD program outcomes to the outcomes of Commercial firms; given that DOD program managers are expected to manage much more complicated and risky programs. However, if DOD program outcomes are expected to measure up to commercial outcomes, the DOD should consider altering its practices to compare to the best commercial practices (e.g. GAO's *KAT)*.

Impact to the Acquisition Community

The results of this analysis should influence the decisions made by the acquisition community. We have validated that adhering to the GAO's *KAT* is an effective way of improving acquisition results. Furthermore, we can interpret that adhering to the *KAT* can help program's produce their products more closely to the originally estimated cost. The GAO's *Knowledge-Based Approach* can help program managers deliver capabilities to the warfighter more closely to their original cost and schedule estimates.

Additionally, the GAO's findings should provide program managers with a substantial reason to freeze requirements early, and to use mature technology. If they can avoid requirements creep and developing technology past Milestone B, they can improve their program outcomes. Ultimately, the warfighter benefits most, because they will get their products quicker and closer to the original cost estimate.

Conclusion

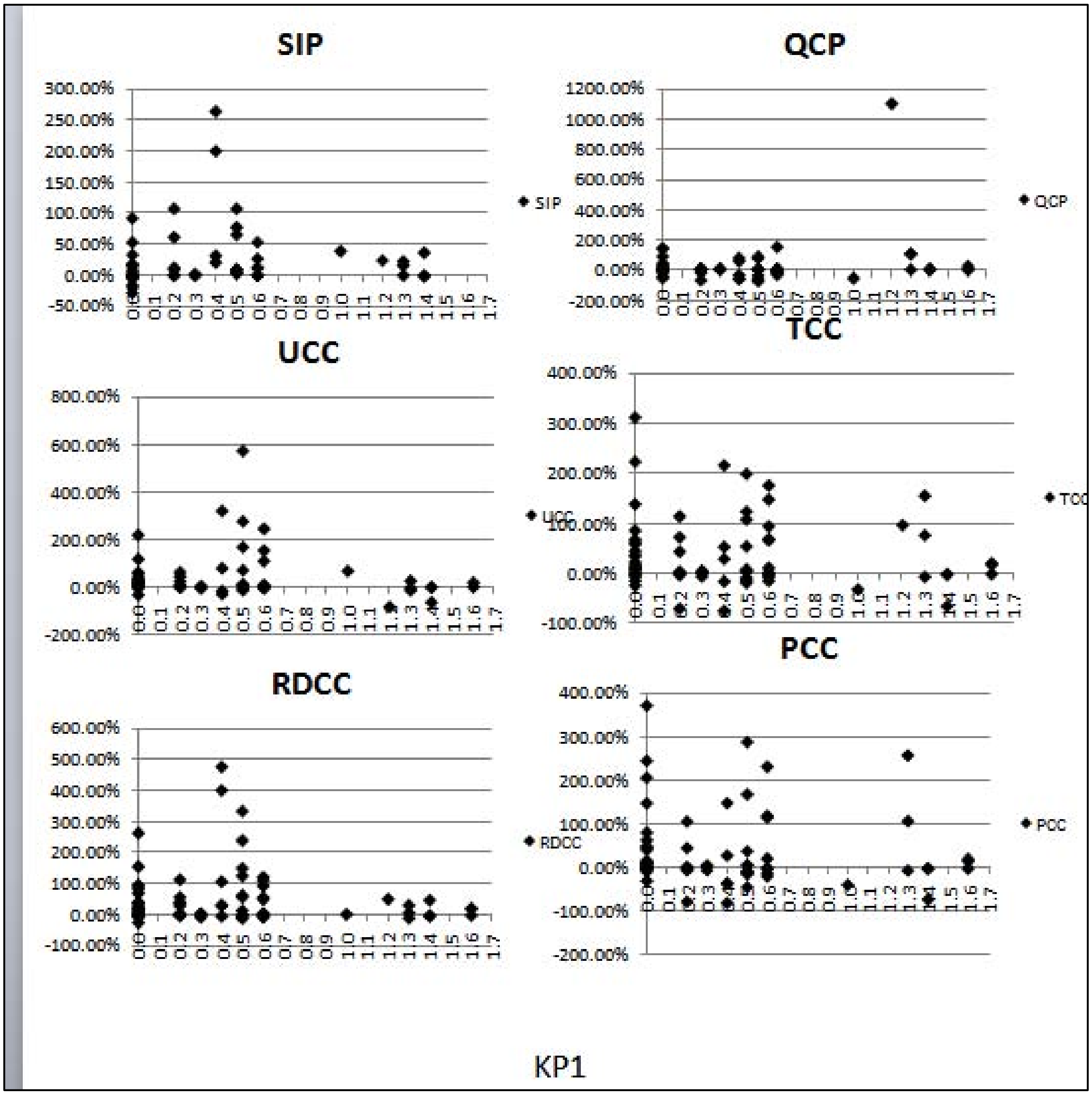
The language contained in the Weapon System Reform Act of 2009 supports the GAO's *KAT* by placing emphasis on using mature technology and conducting trade-offs between cost, schedule, and performance (111-23, 2009). We validated the GAO's *KAT* as a useful means of achieving better program results, but we were unable to validate it as a comprehensive means to better program performance. In our opinion, the *Knowledge-Based Acquisition Theory* is appropriate for DOD programs; it can help them experience better results. However, we also acknowledge that in some cases it may require limiting a product's capability or slowing down the fielding or a product beyond the user's tolerance level. For instance, Quick Reaction Capabilities may not be suited for the *KAT*. Where applicable, the GAO's *Knowledge-Based Acquisition Theory* can help programs experience better results.

Appendix A: Technology Readiness Level's

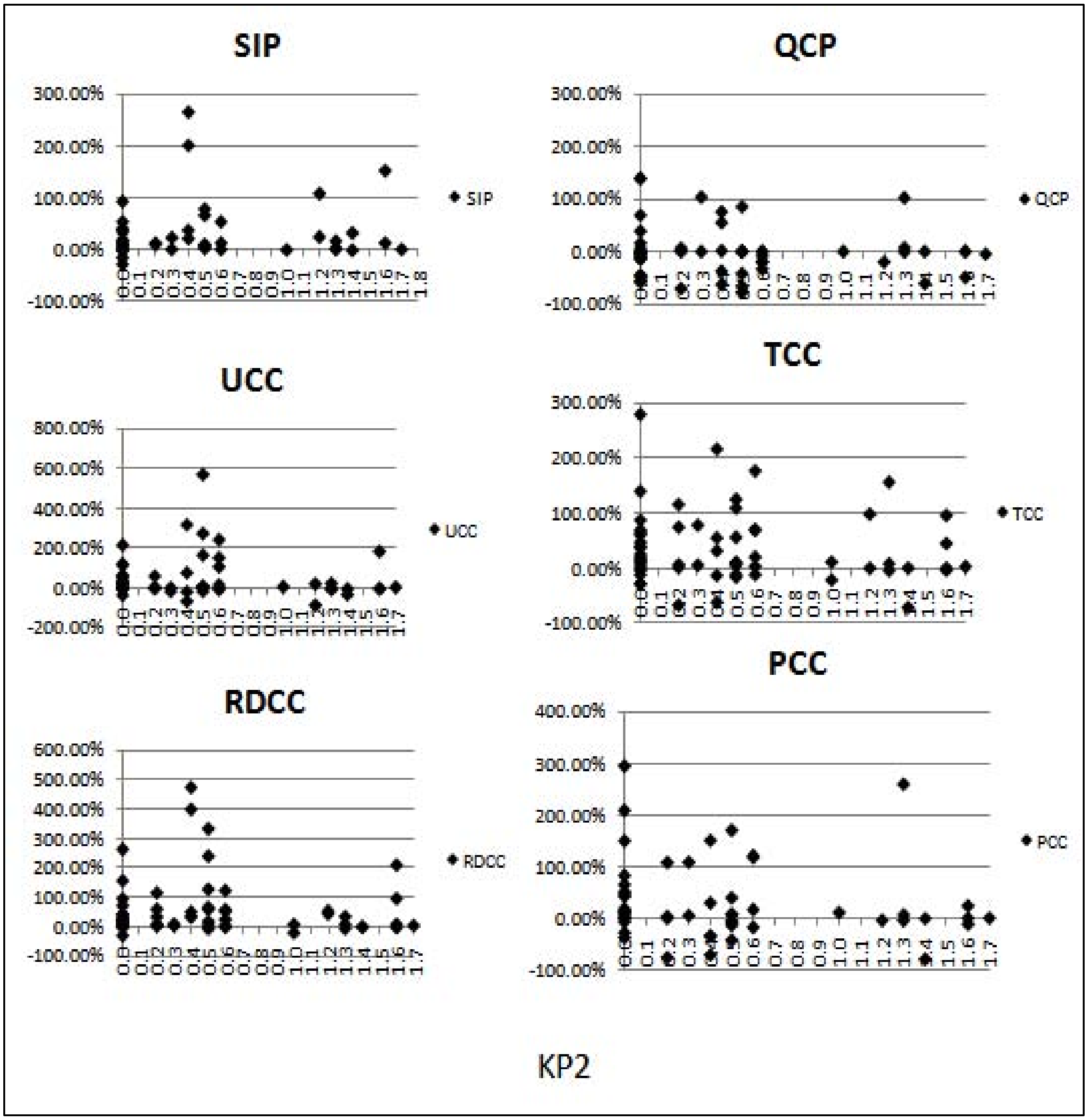
(GAO, 2009, pp. 174-175)

Technology readiness level	Description	Hardware/software	Demonstration environment
1. Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties	None (paper studies and analysis)	None
2. Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.	None (paper studies and analysis)	None
3. Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Analytical studies and demonstration of nonscale individual components (pieces of subsystem)	Lab
4. Component and/or breadboard validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in a laboratory.	Low-fidelity breadboard. Integration of nonscale components to show pieces will work together. Not fully functional or form or fit but representative of technically feasible approach suitable for flight articles.	Lab
5. Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.	High-fidelity breadboard. Functionally equivalent but not necessarily form and/or fit (size weight, materials, etc). Should be approaching appropriate scale. May include integration of several components with reasonably realistic support elements/subsystems to demonstrate functionality.	Lab demonstrating functionality but not form and fit. May include flight demonstrating breadboard in surrogate aircraft. Technology ready for detailed design studies.
6. System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in simulated realistic environment.	Prototype. Should be very close to form, fit and function. Probably includes the integration of many new components and realistic supporting elements/subsystems if needed to demonstrate full functionality of the subsystem.	High-fidelity lab demonstration or limited/restricted flight demonstration for a relevant environment. Integration of technology is well defined.
7. System prototype demonstration in a realistic environment	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in a realistic environment, such as in an aircraft, vehicle or space. Examples include testing the prototype in a test bed aircraft.	Prototype. Should be form, fit and function integrated with other key supporting elements/subsystems to demonstrate full functionality of subsystem.	Flight demonstration in representative realistic environment such as flying test bed or demonstrator aircraft. Technology is well substantiated with test data.
8. Actual system completed and "flight qualified" through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.	Flight-qualified hardware	Developmental Test and Evaluation (DT&E) in the actual system application.
9. Actual system "flight proven" through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.	Actual system in final form	Operational Test and Evaluation (OT&E) in operational mission conditions.

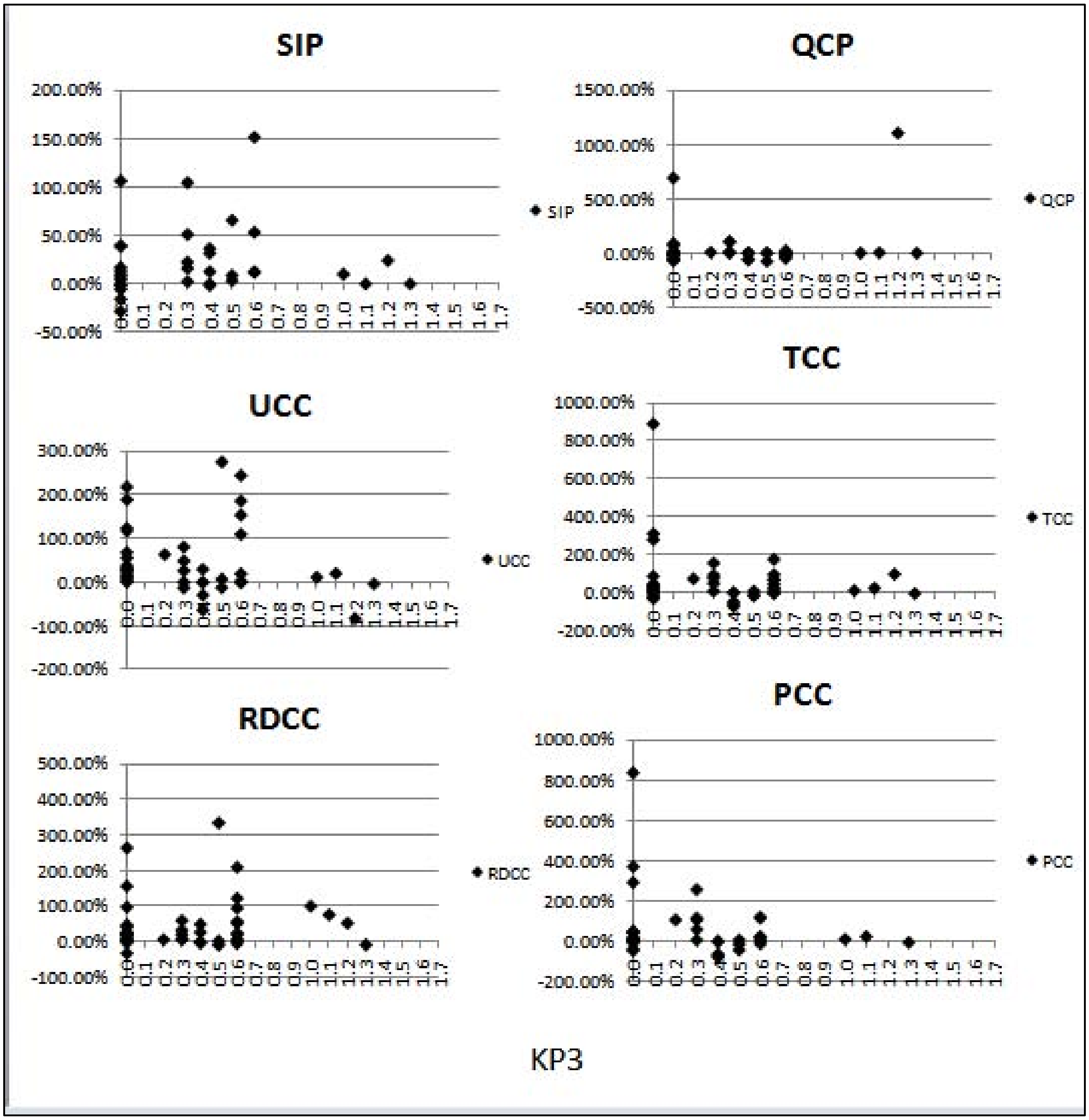
Appendix B: Summary of *KP* achievement by Program Type and Dependent Variable



Missed KP			*Met KP*	
Air	0		Air	1
Land	0.1		Land	1.1
MAIS	0.2		MAIS	1.2
Missile	0.3		Missile	1.3
Munition	0.4		Munitior	1.4
Sea	0.5		Sea	1.5
Space	0.6		Space	1.6
Space/	0.7		Space/	1.7



Missed KP			Met KP	
Air	0		Air	1
Land	0.1		Land	1.1
MAIS	0.2		MAIS	1.2
Missile	0.3		Missile	1.3
Munition	0.4		Munitior	1.4
Sea	0.5		Sea	1.5
Space	0.6		Space	1.6
Space/	0.7		Space/	1.7



Missed KP			Met KP	
Air	0		Air	1
Land	0.1		Land	1.1
MAIS	0.2		MAIS	1.2
Missile	0.3		Missile	1.3
Munition	0.4		Munitior	1.4
Sea	0.5		Sea	1.5
Space	0.6		Space	1.6
Space/	0.7		Space/	1.7

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13. SUPPLEMENTARY NOTES

14. ABSTRACT The U.S. Government has looked for effective ways of reducing acquisition cost and schedule overruns for decades. The task of isolating the root cause of these overruns has been difficult. Consequently, it has been difficult for the Government to create effective policies that prevent overruns from recurring. In 1998, the Government Accountability Office (GAO) undertook this problem, and looked to successful DOD and commercial companies for solutions. They found that using mature technology, having complete product designs, and having production processes under control was critical to successfully developing new products. The GAO combined these concepts into a single acquisition practice that they call a *Knowledge-Based Approach.* They postulate that programs that adhere to the *Knowledge-Based Approach* will experience better program outcomes than programs that do not. This thesis validates the GAO's claim by comparing the outcomes of programs that met the *Knowledge-Based Approach* criteria with those that did not. Our findings suggest that the GAO's claim is accurate. While their approach may not be a single means for success, programs that employed their approach generally performed better. The programs that met the GAO's criteria experienced a smaller variation of outcomes and appeared less likely to spiral out of control.

15. SUBJECT TERMS
Knowledge-Based Approach; Acquisition; Knowledge Point

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